

RESEARCH ARTICLE

Effectiveness of a LED flashlight technique in reducing livestock depredation by lions (*Panthera leo*) around Nairobi National Park, Kenya

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Abstract

The global lion (*Panthera leo*) population decline is partly a result of retaliatory killing in response to livestock depredation. Nairobi National Park (NNP) is a small protected area in Kenya surrounded by a human-dominated landscape. Communities around the park use flashlights to deter lions from their livestock bomas. We investigated the response by lions to the installation of a LED flashlight technique during 2007–2016. We interviewed 80 owners of livestock bomas with flashlights (n = 43) and without (n = 37) flashlights in the surroundings of NNP and verified reported attacks on bomas against predation data over 10 years. The frequency of attacks on bomas equipped with flashlights was significantly lower compared to bomas without flashlights. We also found that after flashlight installation at livestock bomas, lion attacks took place further away from the park edge, towards areas where bomas without flashlights were still present. With increased numbers of flashlight installations at bomas in recent years, we further noticed a shift from nocturnal to more diurnal predation incidences. Our study shows that the LED flashlight technique is effective in reducing nocturnal livestock predation at bomas by lions. Long term studies on the effects as well as expansion of this technique into other communities around NNP are recommended.

Introduction

The global decline in lion (*Panthera leo*) populations has largely been attributed to habitat fragmentation, diminished large prey populations in some areas and retaliatory killing over livestock losses [1–3]. Retaliatory killing of lions has strong repercussions in terms of both declining population densities and disturbed social structures [4,5]. Especially in areas where natural habitat is encroached by expanding settlements and land-use practices, retaliatory killing ranks amongst the greatest threats for lions. Several studies in Kenya as well as in e.g. Namibia and Botswana have reported retaliatory killing of lions by local farmers after livestock

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attacks, due to economic losses [6,7]. In West and Central Africa, lion mortality due to retaliatory killing is a major concern as the few remaining lion populations have reached critically low densities [4,8–10]. For conservationists working in these areas, conflict retaliation has therefore become a main priority [4,7,10,11].

We explored a novel method for reducing human-lion conflict in Kenya. Kenya is a stronghold for lions, with an estimated population of 2,000 individuals in 2008 [12]. With an estimated population of 35 lions including cubs, Nairobi National Park (NNP) in Kenya the lions are surviving despite its relative confinement inside the park surrounded by a densely populated urban area. Although the park is largely fenced [13], an unfenced connection between the southern border of the park and the Athi-Kapiti Plains [14] provides a wildlife migratory corridor and a possibility for lions to roam into surrounding communities. The intensified human demand for space around Nairobi City over the past few decades has led to a spillover of human activities around NNP and the surrounding buffer-zone, which has affected the availability of natural prey for lions [15–17]. At the same time, livestock pressure has intensified, which has led to more livestock incursions into the park and significantly higher portions of livestock in the lions' diet [4,7,10,18]. In 2011, six lions were killed in retaliation by the community south of NNP after livestock was lost to lions (KWS Predation records). Between 2012 and 2016, more frequent attacks by lions on livestock in bomas have been reported and three more lions known to reside inside the park were killed in 2016 in the community land (KWS Predation Records).

Several factors are known to influence the frequency of lion attacks at bomas, including prey densities, season, distance to the park, time of day, livestock herd size, type of livestock and energy cost [8,19–22]. Due to their large body size, lions need large prey to compensate for energy lost during hunting and handling [23]. To maximize the gain, they seek to take advantage of landscape and habitat elements with high prey catchability [24]. In the Amboseli Ecosystem in Kenya, where severe climate conditions have changed and fragmented habitats, large carnivores have shown to increasingly range into communal land, resulting in more frequent reports of human-carnivore conflicts [25]. In other protected areas, e.g. Waza National Park, northern Cameroon [22], Serengeti National Park, Tanzania [26], Pendjari Biosphere Reserve in north-west Benin [8] the distance of a community to the protected area boundary was found to be a determinant of depredation by lions. In Laikipia, Kenya, daytime predation was lowest for small livestock herds with human herders in open fields while predation at night was lowest when livestock herds were held inside decently built enclosures [20,27]. Studies conducted in India, Nepal and South Africa [28] and in Laikipia Northern Kenya [27] further showed that depredation rates could depend on biomass of the domestic prey or on mitigation technique and type of predator and wild prey density, respectively.

Bomas around NNP generally consist of a night-time livestock enclosure fenced with a ring of thorn bushes, wood, post chain-links and/or live vegetation. They are usually owned by one family or related family members with a single herd of cattle and flock of shoats herded together during the day. Some bomas keep shoats and cattle together in one large enclosure but separated with small fence but share one flashlights unit.

In this study we investigated if and how nocturnal attacks by lions on bomas around NNP could be controlled by using the so called LED flashlight technique. This novel method was initially proposed by an 11 year old school pupil named Richard Turere as a measure to prevent nocturnal livestock depredation at their own boma near NNP (see <http://edition.cnn.com/2013/02/26/tech/richard-turere-lion-lights/>). This has received international attention when it was published online as a so called TED talk (see <https://www.youtube.com/watch?v=DdH6L5u2eMM>).

In 2012–2013 the first 19 flashlights were installed in accordance with this technique at livestock bomas along the southern border of the park by NGOs such as The Wildlife Foundation and FoNNAp. As soon as their effectiveness became apparent for some households,

neighboring livestock owners started to use the LED flashlight technique for their bomas. With approximately 30 additional bomas equipped with flashlights by NGOs such as Friends of Nairobi National Park and KWS, the technique slowly became a standard practice for many pastoralists in the surroundings of NNP. As a result, a spatial gradient has become apparent; the closer a boma is located to the park's edge, the more likely it is to have flashlights installed. As of yet, the installation of flashlights in the study area has not been systematic and is not part of any official protection scheme.

Although similar techniques have been used in other areas to deter carnivores and birds, either from livestock, crops or other properties (see <http://www.niteguard.com>, <http://predatorguard.com> and <http://www.foxlights.com>), the application of lion deterrence lights is the first in Africa to our knowledge. The system uses a solar panel to power a series of LED flashlight bulbs connected by cable wire (Fig 1). Depending on the size of the boma, a car battery supplies energy to 4 to 6 bulbs mounted on several outward facing poles along the livestock boma perimeter. The flashlights are set to continuously flicker at a rate which is to mimic a livestock guardian holding a flashlight and walking on foot around the boma. To equip one livestock boma with flashlights, an investment of approximately \$250 is required (Nickson Parmisa personal comm.).

We hypothesize that the presence of flashlights would reduce the frequency of lion attacks at livestock bomas during the night, and could lead to behavioral changes in livestock raiding lions. Such behavioral changes could include avoidance strategies in which lions would move greater distances from the park boundary in search for bomas that are not equipped with flashlights, or a certain level of habituation to the flashlights. An attack is defined as a livestock predation incidence leading to either death or injury to one or more heads of livestock (cattle, donkeys, or shoats). A boma is a Kiswahili term for a livestock or household compound enclosing structure [29] for an overnight livestock protection against predators constructed with tree branches, wood, poles and/or chain-link material. In this paper we use the term "shoats" for a mixed flock of sheep and goats.

Materials and methods

Study area

Our study was conducted in the Kitengela triangle in Kenya, adjacent to the southern part of NNP. The study area is situated between latitudes S013.9054° to S01.15162° and longitudes E036.8251° to E036.9681° at an altitude ranging from 1495m to 1684 m above sea level (see Fig 2). The eastern part of the study area is defined by the Athi river export industries processing zone and the Kitengela River. The western part is characterized by two high density human settlement areas; Rongai and Twala.

The study area is rich in soil nutrients and receives a mean annual precipitation of 780mm [15]. The riverine vegetation is dominated by *Acacia xanthophloea*, *Acacia mellifera* while plains are dominated by *Balanites* tree species and *Themeda* savanna grassland [15,30]. The Mbagathi and Kiserian rivers are tributaries of the Athi River and both provide a permanent water source. The study area is a wildlife dispersal zone and is part of the Athi-Kaputiei plains. It covers a surface area of 2,200 km² [31]. The Kitengela triangle, which consists of 390 km² of open grassland, is the first stop-over for annual migration of the blue wildebeest (*Connochaetus taurinus*); Burchell's zebra (*Equus burchelli*); and other ungulates such as common eland (*Tragelaphus oryx*); coke's hartebeest (*Alcephalus buselaphus*); Grant gazelle (*Gazella granti*) and reticulated giraffe (*Giraffa camelopardalis tippelkirchi*) in the wet season [30].

The local communities in the study area are mainly represented by traditional transhumance pastoralists, mostly of Maasai origin. Unlike the exclusive pastoralists in the Maasai Mara as

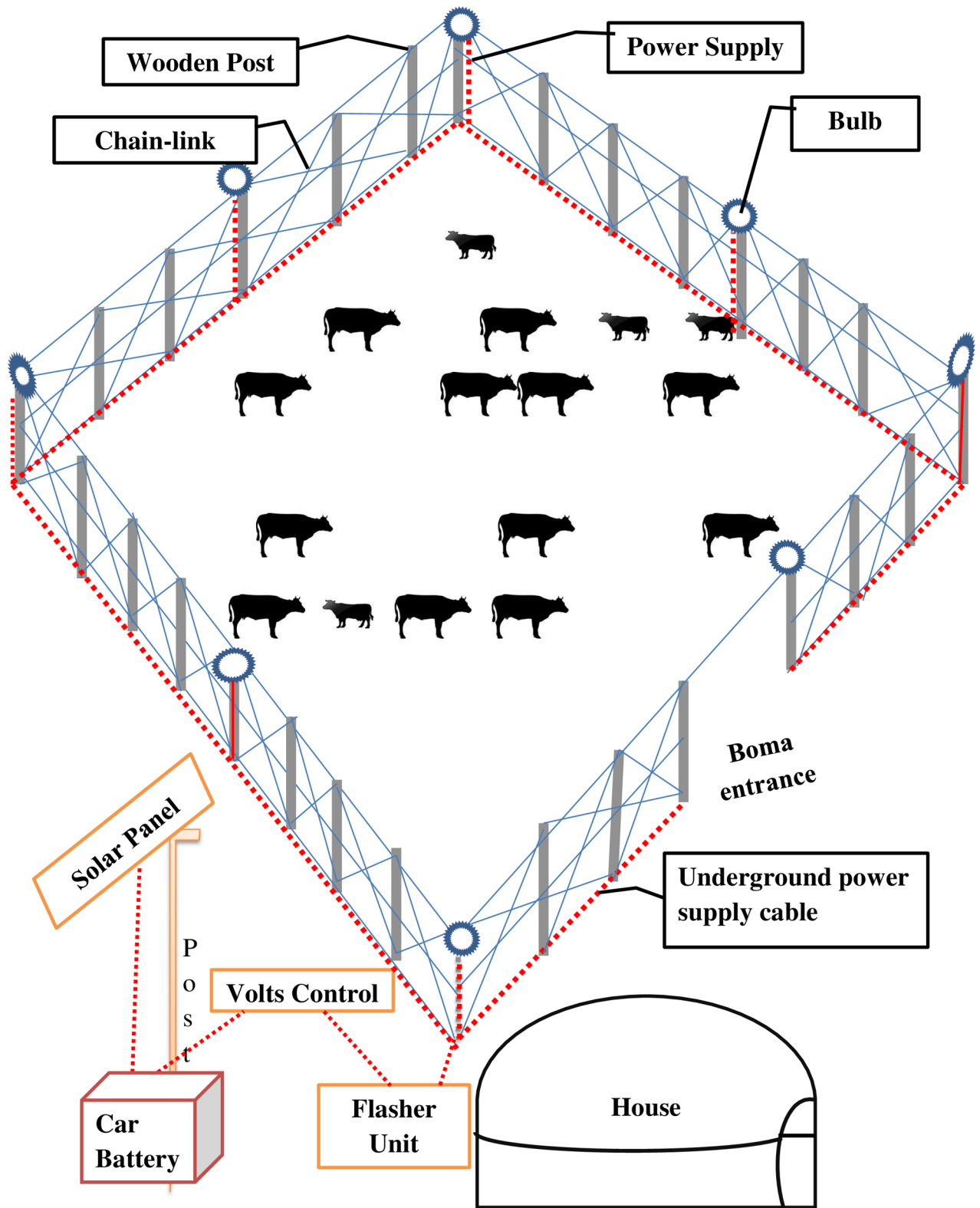


Fig 1. A drawing of a livestock boma with flashlights installed. The car battery is powered by a solar panel. The bulbs at the fence perimeter are connected through a wire from the flasher unit to flicker at night.

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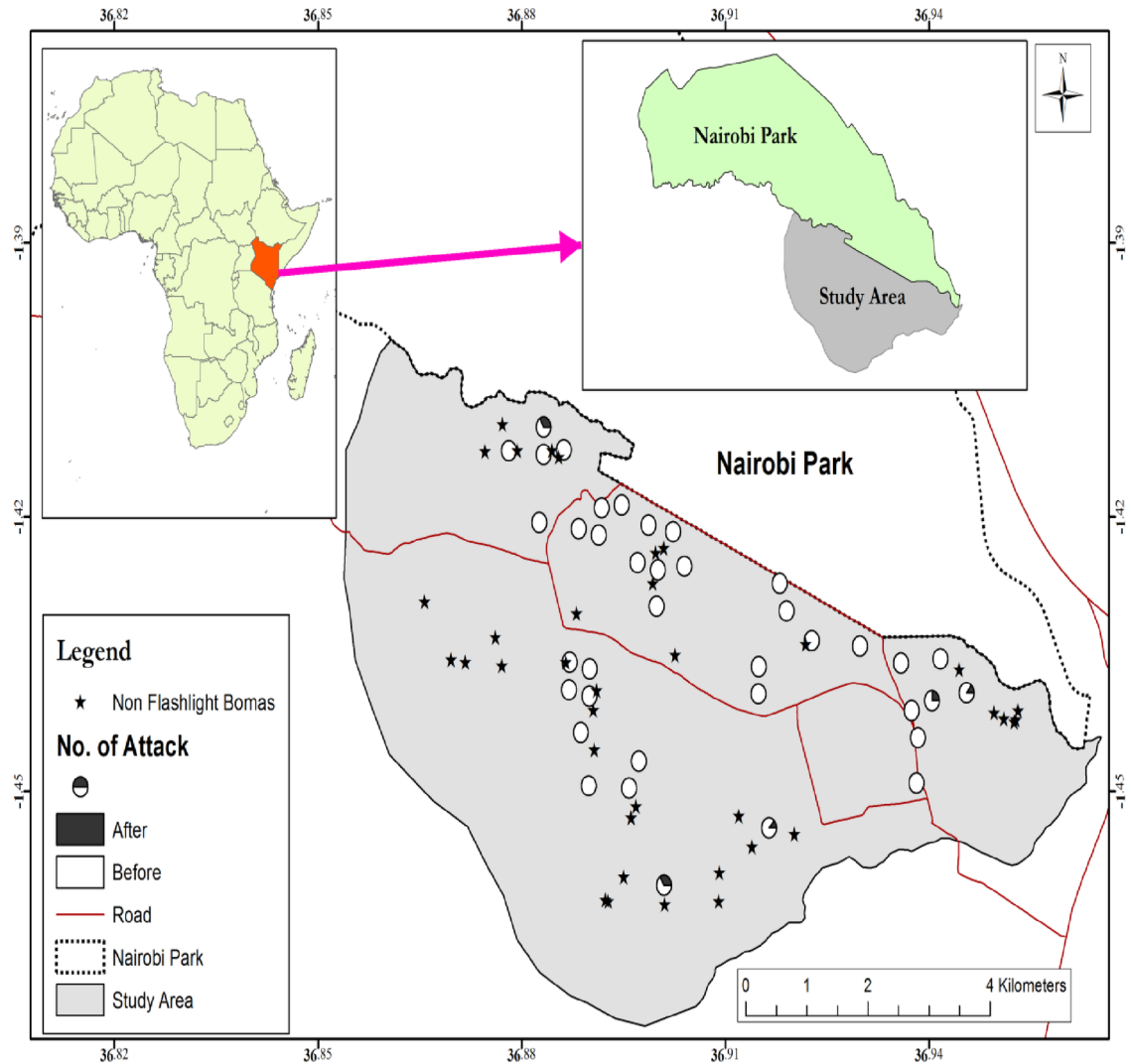


Fig 2. A map of the study area showing the proportion of boma attacks prior to and after installation of the flashlight technique. Empty circles (○) represent bomas where attacks had been reported before installation and none after installation. The partly filled circles (◐) represent bomas where attacks took place after flashlight installation. The stars (★) represent bomas of interview participants without flashlights.

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described by Kolowski and Holekamp *et al.*, (2006) [32], the communities in our study area are sedentary; families or households are staying in one location for an extended period of time. During the day, cattle and shoats from different households share communal grazing fields and do not share a boma at night. Each boma owner has own separate enclosures for shoats and cattle. Guided by a few male household members they migrate to neighboring counties in search for pastures and water. During this time, only few shoats or cows are kept in bomas for milk.

Ethics statement

This research did not involve invasive or intrusive methods; no financial inducement for information, personal data, involvement of vulnerable groups (children, mentally disabled) of the society. Interviews were conducted in a transparent manner, voluntarily and with participants consent. The ethical conduct of the interviewers was verified and confirmed by the PhD

supervisors during field visits. The research has been approved by the Graduate School of Leiden University, the Faculty of Science and the Directory Board of the Institute of Environmental Sciences in Leiden (Ref HDI/634/2014).

Data collection

Data were collected from 43 bomas for which flashlights had been installed at the initiative of individual livestock owners or by NGOs such as Friends of NNP during 2012–2016 (Fig 2). During the time of our research, the number of bomas with functional flashlights varied to some extent, as additional flashlights were installed while some flashlights broke down. In our analyses we therefore only included bomas which had functional flashlights during the full period of our research.

Since no official records are kept on the number of bomas with flashlights installed in the study area, this information was collected during a survey by car and on foot, which we conducted before the start of the interviews. We used Arc GIS v.10.2.2 (ESRI, Redlands, USA) to plot the GPS locations of all bomas with or without flashlights in the study area. Households were selected from this semi-randomly, taking care that the entire buffer zone was covered equally. The interviews covered 12% of livestock owners in the Kitengela corridor, who kept livestock in a boma within a distance of 5 km from the park boundary (Fig 2). We interviewed one person in case different families share one boma protected by one flashlights unit to avoid biasness.

During April 2014, we interviewed a total of 80 boma owners south of NNP including the 43 bomas with flashlights. All households interviewed in 2014 were interviewed again in 2016, though sometimes with different respondents. The questions specifically aimed at techniques and measures used to deter predators or otherwise protect livestock from large carnivore attacks. We used a known dataset of lion predation cases that had been reported around NNP between 2007 and 2016 to KWS, FoNNaP and TWF, as part of the Wildlife Conservation and Management Act (2013), and the Wildlife Lease Conservation (2000–2012) and Consolation (2008–2012) program respectively, to verify the results of our questionnaires.

Each interview consisted of a pre-structured questionnaire for which the questions had been translated from English to Maasai and Swahili language (S1 File) and which were posed by two native research assistants. The 2014 questionnaires were enhanced in 2016 with a few additional variables (S1 File). The number of livestock per boma, fence materials used (thorn, wood, chain-link, live plants and mix), fence height (0–1.5 m, above 1.5 m), transparency of the fence (visibility of livestock) as in Woodroffe *et al.* (2007) [20] were only addressed in the questionnaires of 2016 (S1 File). We only interviewed owners of single bomas containing the livestock they owned either with or without flashlights. Bomas included in the predation data which were not mentioned during the interviews, were excluded from the analyses. The unit of analysis was “boma-owner”.

Data analysis and statistics

In order to isolate the effect of flashlights on the probability of a boma attack by a lion, we first identified confounding variables, possibly explaining the probability of a boma attack. These confounding variables were defined as (i) bomas with flashlights and without flashlights, (ii) distance of boma to the park boundary, (iii) timing of the lion attack in terms of day and night attack, (iv) mean yearly rainfall, (v) fencing materials used by the boma owners, (vi) numbers of livestock in a boma, (vii) year of flashlights installation. Our response variable was in all cases ‘the probability of attack per year’, expressed as the number of bomas attacked in a year, divided by the number of all bomas present within a 5 km zone from the park boundary in that year. We made a distinction between boma with flashlights and boma without flashlights.

All data were tested for normal distribution with a Shapiro-Wilk test for normality. For bomas with flashlights installed, we calculated the mean number of attacks prior to and after flashlight installation by dividing the number of attacks by the number of years with and without flashlight. A Wilcoxon rank and paired test was used to test the significance. We tested the intensity of attacks between bomas with flashlights and those without flashlights using a chi-square test.

To determine other factors that could affect the probability of an attack, we developed a case specific general linear mixed model (GLMM). The dependent variable in this model was a binary variable indicating whether the boma was attacked at night during a certain year or not. Independent variables were defined as “presence of a flashlight”, “year” (as a scale variable), “mean rainfall” and “distance to the park boundary”. “Year” (as a factor) and “Boma code” were used as random factors. The model-family was binomial using a logit link. For testing the significance of the different stable factors, we applied a likelihood-ratio test (LRT). For fitting the model we used `glmer` from the `lme4`-package (Bates and Maechler, 2010) in R (R Development Core Team 2017).

The distance of a boma to the park boundary was determined from coordinates obtained with a global positioning system (Garmin eTrex 20) and Arc View v.10.2.2 (ESRI, Redlands, USA). The bomas were classified into four distance categories: (i) near (at 0–1 km); (ii) intermediate (at 1–2 km); (iii) far (at 2–3 km) and (iv) the furthest (at more than 3–4 km from the park). For each of these categories we calculated the average probability of attack over 10 years. The differences were tested with a Mann-Whitney U test (p-value 0.005) (Bates and Maechler, 2010) in R (R Development Core Team 2017).

We compared the average probability of attack during the night versus at daytime using a Mann-Whitney U test. The change in probability of diurnal versus nocturnal boma attacks over the years was studied by calculating the probability of diurnal and nocturnal attacks per year, thereby assuming that every boma has an equal chance of being attacked. Thus, we calculated the number of attacks per night by dividing the total number of yearly attacks by the number of days (365) in that year and multiplying it by the number of bomas (80). The resulting probabilities were tested using a chi-square test. We also tested diurnal livestock attacks prior to installation flashlights and diurnal attacks after installation using a chi-square test.

Changes in probability of a boma attack over time in relation to distance to the park were calculated based on yearly mean distance to the park of the attacks. The trend in these distances was tested through a linear regression model using R statistics. Each boma was given a reference number (boma code) which ensured individual bomas could be recognized while protecting the boma owners' identities.

In the absence of accurate local density estimates for prey, we used annual rainfall as a proxy for the prey density, based on the assumption that in wet years, large prey species are leaving the park into community land, driven by more equally distributed water and graze resources [19]. The relationship between the amount of rainfall (mm) and the frequency of attacks was analyzed using a Pearson correlation (p-value 0.05). We averaged the number of nocturnal attacks by fencing category and applied a chi-square test.

For the analysis on livestock herd size (sheep and cattle) we used reported livestock herd sizes during the 2016 interviews to average herd size and classified these as “small” when below mean herd size and “large” when above mean herd size. We used a Kruskal test to test the significance.

Results

A total of 814 livestock were reported killed by lions between 2007 and 2016. Interview respondents reported a total of 413 depredation cases related to lions during this period, and these

were confirmed against KWS predation records. In the 413 reported cases, 308 (75%) cases occurred at during the night and 105 (25%) during the day. The 43 bomas where flashlights had been installed during the course of this study, 184 (96%) attacks took place prior to flashlight installation and 7 (4%) after flashlight installation (Wilcox paired test $W = 780$, $p\text{-value} < 0.0001$, Fig 3 and S1 Fig). The probability of an attack on bomas without flashlights is significantly higher compared to bomas with flashlights ($\chi^2 = 10.369$, $df = 4$, $p\text{-value} = 0.035$) (Fig 4). Twenty three percent (23%) of the respondents who reported predation after flashlight installation, had not suffered any previous livestock losses at the bomas and 68% had no flashlights installed. Of the 105 diurnal predation cases, 21 (20%) occurred prior to flashlight installation (2007–2011) and 84 (80%) after flashlight installation (2012–2016, $t = 2.47$, $df = 61.11$, $p\text{-value} = 0.016$). Fig 5 shows the shift in time (nocturnal to diurnal) in livestock depredation prior to and after cumulative installation of the flashlights. There appeared to be a pronounced peak in predation during 2012 (55 cases).

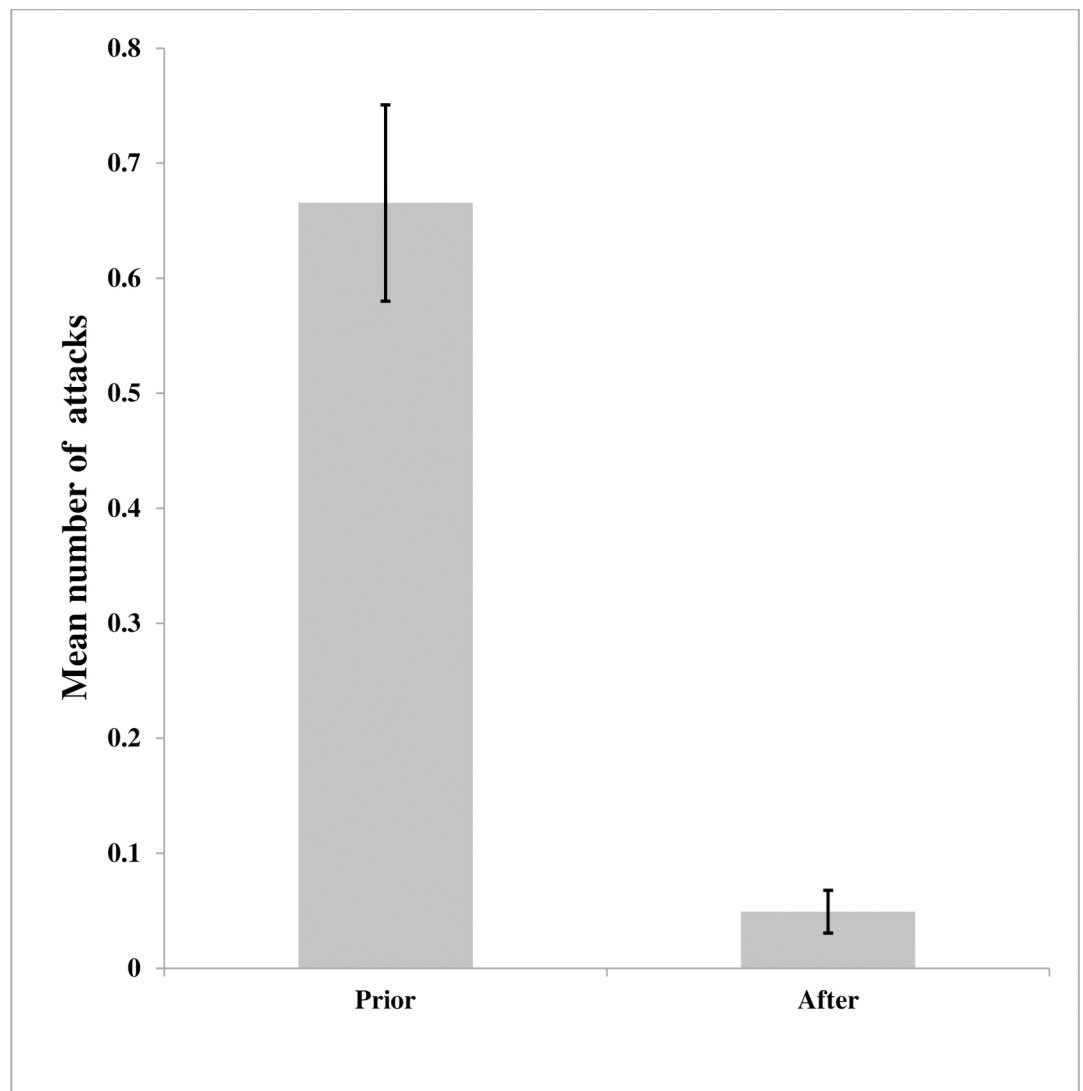


Fig 3. Mean number of attacks (\pm sd) by lions prior to and after installation of the LED flashlight technique based on 43 bomas with flashlights.

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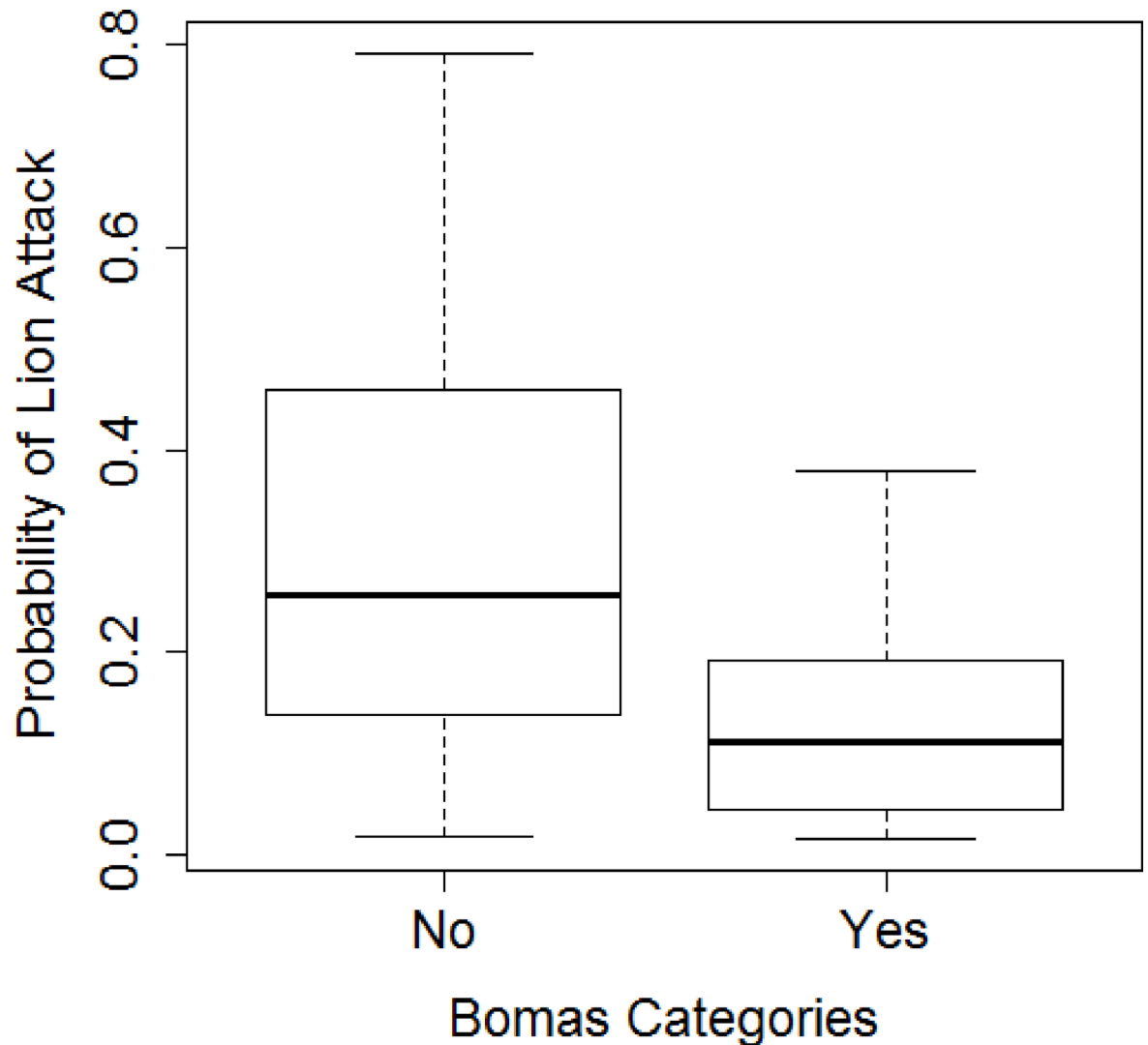


Fig 4. Difference in the probability of lion attacks between the two categories of livestock bomas, (Yes = with Flashlight, No = without flashlight) between 2007 and 2016 based on GLMER model.

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The mean rainfall, distance of the boma from the park, years, and flashlights were all significant (see Figs 4, 5 and 7, and S1 Fig) on each of the variables of attacks (Table 1). Whereas the period of working flashlights in a boma has high probability of reducing nocturnal livestock attack, finding shows that the shorter the distance of the boma from the park border the higher the intensity of attack while the yearly increase in the attack is due to lion changing the behavior of looking for bomas without flashlights. The number of boma attacks is related to the presence of flashlights ($\chi^2 = 12.975$, $df = 1$, $p\text{-value} = 0.0003$).

Analyses showed a significant positive relationship between rainfall and the number of attacks on livestock per year (pearson's correlation test; $t = 157.11$, $df = 725$, $p\text{-value} < 0.001$ (S1 Fig), with a significantly lower probability of attacks in 2009, which had extremely low rainfall (59.2 mm), as compared to 2012, when rainfall was relatively high (102.6 mm).

Bomas at a distance of 3 km or more from the southern park border were attacked significantly less often compared to bomas located closer to the park (Fig 6). The percentage of

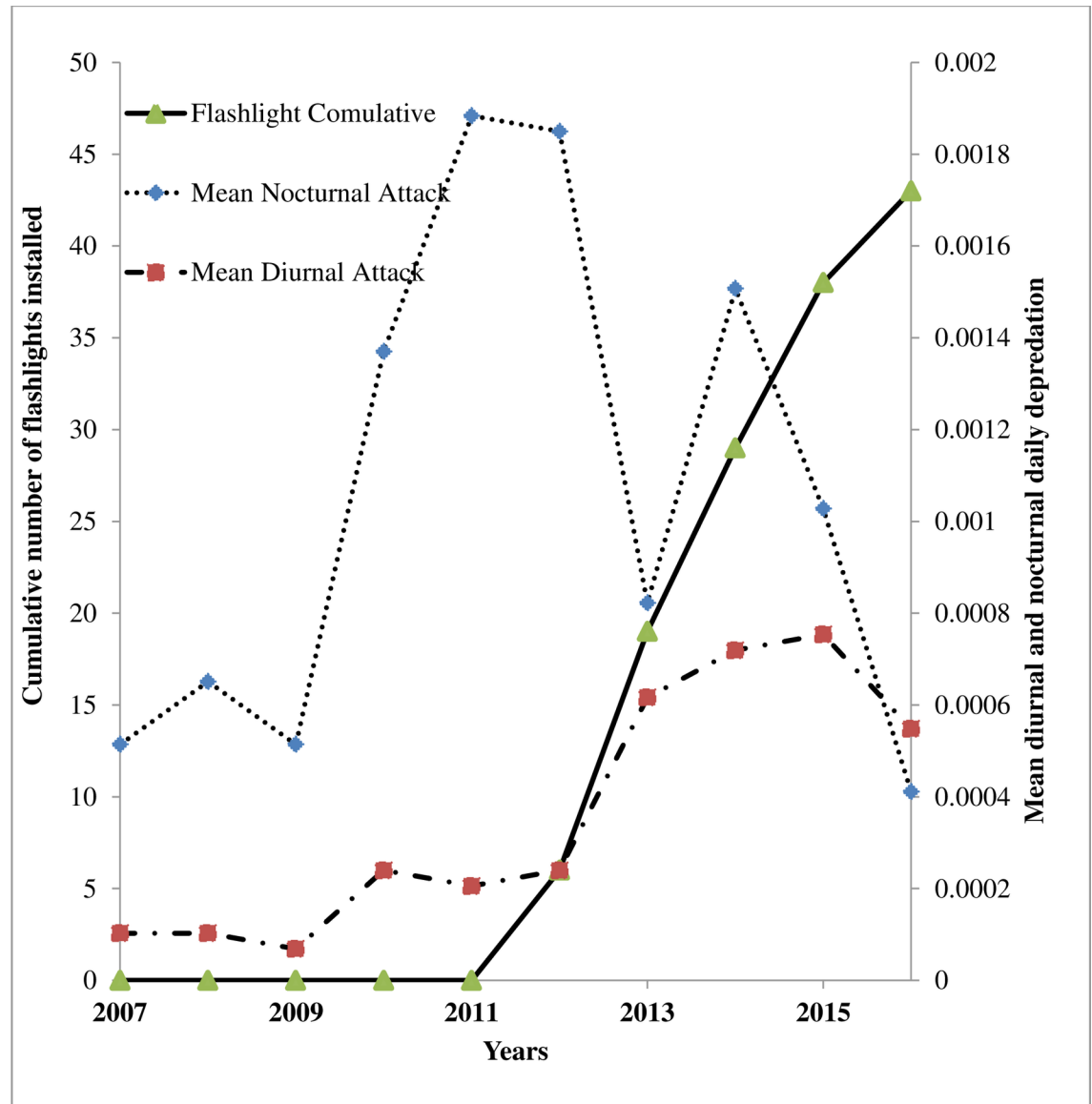


Fig 5. Cumulative flashlights installed and Mean nocturnal and diurnal livestock predation at bomas with and without flashlights.

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attacked bomas ranged from 54% (at 0–1 km); 31% (at 1–2 km); 11% (at 2–3 km) to 4% (at >3 km from the park boundary). We also found a significant yearly increase in mean distance of attacks from the park boundary, from the application of flashlights in 2012 (Mann-Whitney U test $t = 11.291$, $df = 79.002$, $p\text{-value} = 0.0001$) (Fig 7). The yearly regression with intercept of $2.001+03$ and slope of 0.008 , shows that every 3 years, there is 2km increase in distance of attack.

The fence height in relation to percentages of attack (high = 12%, medium 23%, short = 71% and $\chi^2 = 8.088$, $df = 2$, $p\text{-value} = 0.017$). This shows that bomas without flashlights and those with short-medium fences are more likely to be attacked by lion than those with flashlights and higher fences. The data normality distribution test was $W = 0.87567$, $p\text{-value} < 0.00001$.

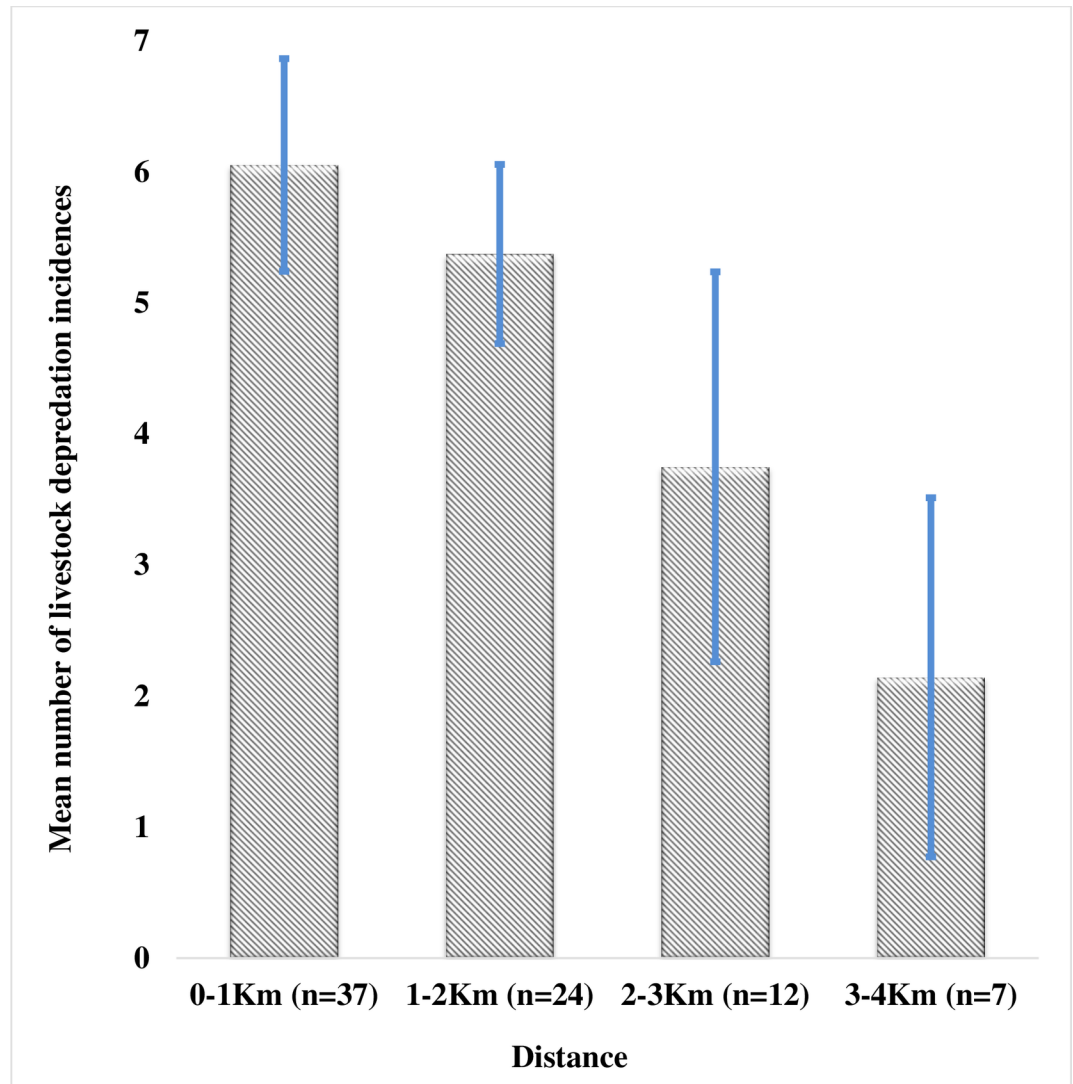


Fig 6. Mean number of nocturnal and diurnal boma attacks around NNP between 2007 and 2016 at different distances from the park boundary.

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Bomas constructed with high wooden post supported by chain-link ($\chi^2 = 8.1131$, $df = 1$, p -value < 0.005) and barbed wire with post fence, were attacked less frequently than the other categories ($p < 0.05$, Fig 8). None of the other deterrence variables (scare crow, dogs, spotlight,

Table 1. GLMER showing the significance variables in relation to predation around the park using likelihood ratio test.

Variables	Df	AIC	LRT	Pr(Chi)	Significance
Flashlight	1	743.92	14.303	0.0001556	***
Years	1	742.83	13.220	0.0002770	***
Mean Rainfall	1	741.64	12.029	0.0005237	***
Park Distance	1	743.95	14.333	0.0001532	***

Significance codes: 0 '****', 0.001 '***', 0.01 '**', 0.05 '.', 0.1 ' ', 1 '***] represents the reference variable.

Model 1: Attnight ~ Flashlight + Year + Mean Rainfall + Park Distance+ (1 | Code) + (1 | Years)

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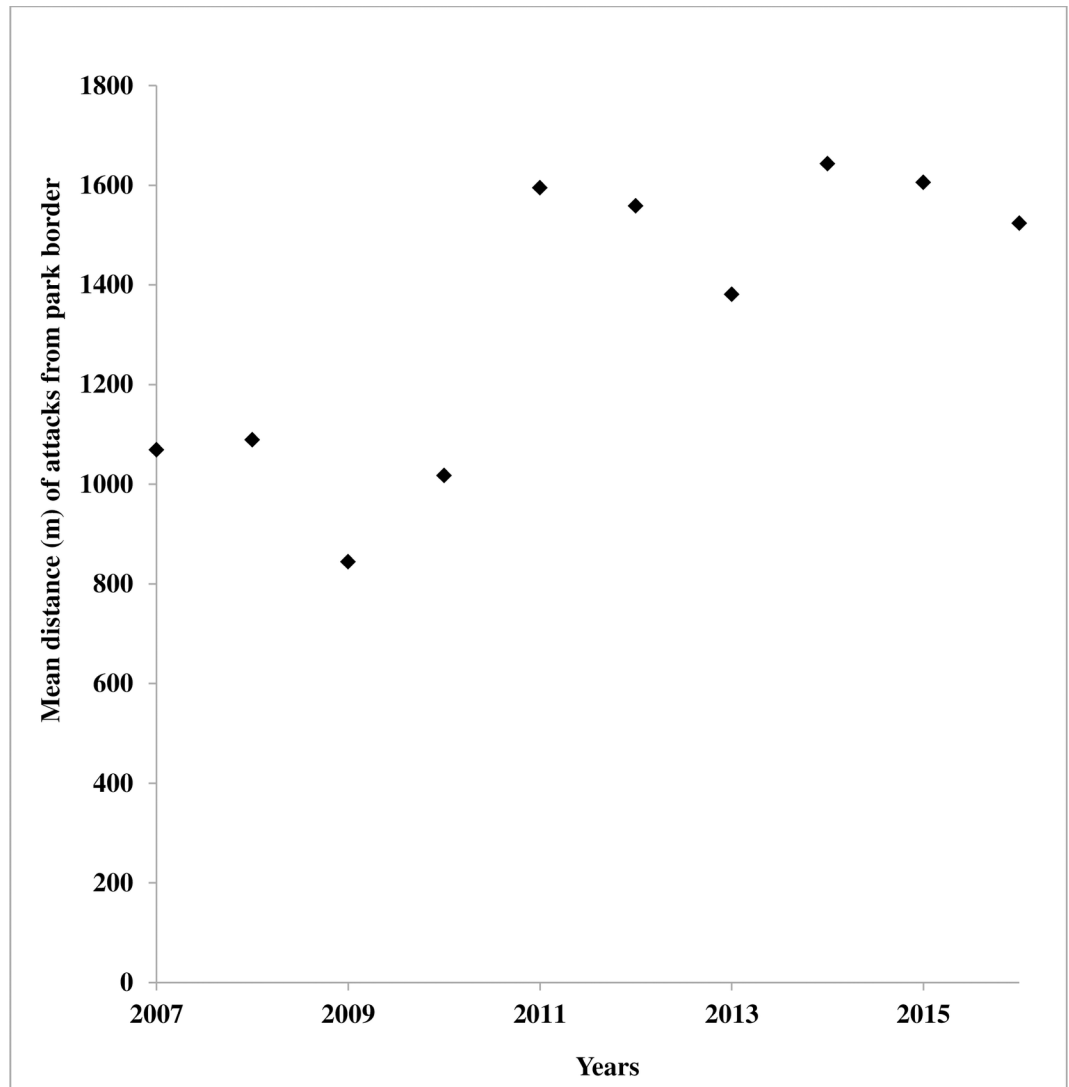


Fig 7. Yearly mean distance of boma attack from the park boundary since the introduction of the flashlight technique south of NNP.

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radio, fire and noise) were significant in predation prevention (see [S1 Table](#)). Herd size did not affect nocturnal predation of shoats (Kruskal test, $\chi^2 = 21.76$, p-value = 0.7) and cattle ($\chi^2 25$, p-value = 0.6) (see [S1 Table](#)).

When respondents were asked an open question on what they believed should be done to resolve human-lion conflicts around NNP, (Appendix I, question 13), most respondents (92%) had one or more suggestions ([S3 Table](#)): “flashlight installation” and “some form of compensation” were by far the most mentioned suggestions, followed by measures that would prevent lions from roaming outside the park boundaries. Although “fencing the park” was sometimes mentioned, 62% of the respondents did not believe that complete fencing of the park would resolve the human-lion conflict. Suggestions further included measures that could rapidly detect and relocate freely roaming lions back to the park, which according to some will become even more important when the announced plans for the construction of a railway through NNP (in the northern area) will eventually take effect.

Discussion

The highly significant decline (96%, Figs 3 and 4) in lion attacks on bomas with flashlights installed, confirmed by positive experiences from the majority of interviewed owners of such bomas (92%) support the hypothesis that flashlights reduce the probability of nocturnal lion attacks at livestock bomas. Secondly we found a change of lion behavior, which shifted their attacks to attacking non-flashlight boma's or by shifting from nocturnal attacks to diurnal attacks (Fig 5).

At the same time, lions covered greater distances from the park boundary, towards areas where bomas had no flashlights installed (Fig 7). This, in combination with the shift in timing from predation at night to attacks during the day (Fig 5), suggests that lions in the study area actively search for livestock bomas with no flashlights installed, thereby avoiding those with flashlights. Our findings have great implications for livestock owners in the region, especially for those who have no flashlights installed at their bomas. The losses suffered as a result of the shift from nocturnal to diurnal attacks, are however generally small and could be addressed by relatively simple changes in herding strategies during the day [20,33,34].

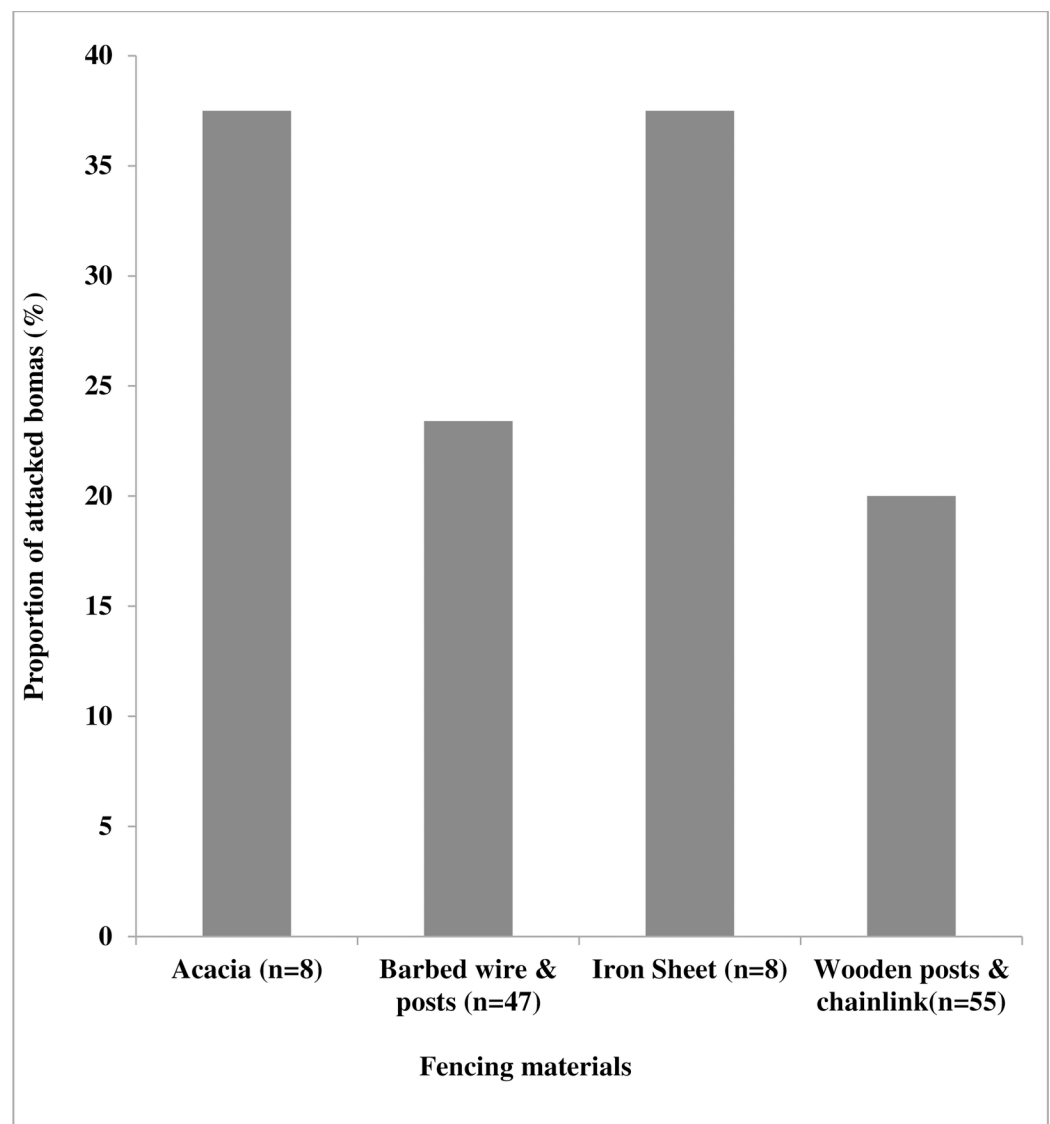


Fig 8. Proportion of reported attacks on bomas at night for each type of livestock fencing materials.

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Similar to results from other studies [4,22,35], our findings show that increased rainfall is related to higher livestock depredation frequencies. This is a common phenomenon which is associated with a greater dispersal by both lions and their natural wild prey species during the wet season due to an increased and more widespread availability of both water and pasture after the rains [19]. Rainfall in the study area was highest during the 2011–2012 season, which was also the peak for livestock depredation.

Despite the great variation in reports on the importance of boma characteristics and construction materials [20,27,35] in the prevention of attacks on livestock by large carnivores, it is generally agreed that improved enclosures as well as both night and day time vigilance reduces the rate of livestock depredation [7,8,10,20]. The improved fencing techniques used in studies such as “Living walls bomas” [35,36] and “predator-proof bomas” [29] demonstrated success rates which were similar to what we found after flashlight installation; a 90% to 99.9% decrease in nocturnal lion attacks. However, the outcome on the use of dogs by the community around NNP is contrary to that of van Eeden *et al.*, (2017) [37] who found that use of animal guidance to prevent livestock attack. Our study further demonstrated that boma attacks by lions could at least to a certain extent be prevented by using wooden fencing materials, reinforced with chain-link perimeter fencing material, if constructed at a height of at least 2.5 m and when livestock visibility from outside was poor. Respondents with few shoats (<20) used iron sheets, or concrete walls and roof covered bomas to minimize chances of lions climbing over.

In individual cases however, replacing traditional thorn-bush fencing by high concrete or chain-link materials has been reported to cause actual losses of livestock to be greater. During the course of our study a lion was observed by the principal author to climb over a chain-link fence of 2.5 meters surrounding a boma where no flashlights had been installed to predate on the livestock that was kept inside. Several additional reports of attacks on bomas that were covered by roofs of chain-link material described cases in which a lion would climb the chain-link roof and then fall through the chain-link barrier, into the boma, where the livestock was trapped. While livestock would still be able to escape from a boma that is built with thorn fencing, thereby minimizing catchability and number of casualties, the chain-link fence and roof provide no escape route at all. A lion trying to escape a death trap like this, is likely to kill and injure even more livestock in the boma.

Whereas in our study livestock herd size did not influence nocturnal boma attacks by lions, findings of Van Bommel *et al.*, (2007) [22] suggest that the number of livestock present in a village is directly related to the number of lion attacks. Woodroffe *et al.*, (2007) [20] also found that a large livestock herd size is associated with a higher risk of diurnal predation. Although the frequency of attacks on livestock is generally higher closer to the park boundary (as was found for e.g. Waza National Park in Cameroon [22], Serengeti National Park [26] in Tanzania and Kweneng in Botswana [38], lions would cover up to 20 km per day in search for prey [25], thereby entering high-risk, human-dominated areas to kill livestock [27,39].

As previously stated in our study, lions show highly adaptive behavior to the installation of flashlight bomas, with the shift to non flashlight bomas further away from the park boundary and the shift from nocturnal to diurnal attacks. We expect that due to these adaptations the damage to livestock owners may decrease in the coming years, since less livestock is killed outside bomas during daytime, and we expect a further increase in the number of flashlight bomas.

Conclusion and recommendation

Despite the effectiveness of our proposed LED flashlight technique in deterring lions from livestock bomas around NNP, its successful implementation in a different situation is not

guaranteed. Conflict mitigation techniques that are effective in one place could fail in another, and even at a local scale, measures could become less effective over time, due to changes in e.g. environmental or social factors [34]. Eklund *et al.*, (2017) [40] suggested that a single intervention is usually not a long-term solution to human-wildlife conflicts. Livestock owners should be aware of this and ensure they have multiple anti-predation techniques in place at any given time [34,41]. Working together with local authorities in managing such techniques, but also the implementation of rapid response mechanisms and simply ensuring that faulty flashlights are being serviced, are all additional aspects that can be crucial for any mitigation measure to be effective [34]. Whereas evidence based lethal control measures to ban lions from villages have historically been recommended [37,41], for the pastoralist communities around NNP this certainly has no preference. The majority of livestock owners we interviewed suggested non-lethal techniques could and should be used to effectively reduce livestock predation rates in the area.

The usefulness and applicability of the LED flashlight technique in other parts of the world, and thus to other species of large carnivores, would be worth exploring. Although differences in behavior, habitat and range use have to be considered, we believe our technique when adapted, it has the potential to effectively reduce attacks on livestock by conflict prone large carnivores e.g. spotted hyenas (*Crocuta crocuta*), leopards (*Panthera pardus*), tigers (*Panthera tigris*), or even coyotes (*Canis latrans*) and foxes (*Vulpes vulpes*). The loss of these apex predators would have a cascading effects on ecosystem functioning, economic services and an intrinsic value which they either contribute directly or indirectly [42].

The recent increase in the number of lion attacks at unprotected bomas has a great impact on the livelihoods of local communities. In fact, six recent reports of lions sighted in the suburbs of Nairobi City, prove that today's challenges associated with human encroachment around NNP are greater than ever before. In the current situation, the pressure on bomas without flashlights further away from the park boundary or in new areas which experienced very few or no lion attacks before, is likely to further intensify, unless the proposed LED flashlight technique were to be implemented and reinforced throughout the lions' dispersal range by national and county governments. Future studies on the effectiveness of our technique should take this behavioral adaptation of lions into account and should ideally include a control sample of bomas with no flashlights installed.

Supporting information

S1 Fig. Annual mean rainfall (mm) correlation with total number of annual livestock depredation cases by lions from 2007–2015 at southern part of NNP. The higher the rainfall, the more predations.

(TIF)

S1 Table. Complementary predation defense deployed by the livestock owners at night based on the 2016 interviews.

(DOCX)

S2 Table. The livestock herd size, number of attack and cases without attack.

(DOCX)

S3 Table. Participants' opinion on how to resolve human-lion conflicts.

(DOCX)

S1 File. Final questionnaire.

(DOCX)

S2 File. Statistics (8).
(XLSX)

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